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Experiments with a Data Weighting Scheme for Satellite Soundings

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I. Introduction

One of the obvious deficiencies of the Flattery operational objective analysis method used in the NMC Final cycle is its inability to systematically weight data of differing type and quality with the forecast used as first guess to the analysis. This deficiency will become more glaring as each new observing system, with its own unique set of error characteristics, becomes operational. The biggest source of new data during the next few years will probably be satellite derived soundings. This paper reports on an experiment in which an attempt was made to systematically weight satellite soundings with the forecast first guess in the NMC operational objective analysis/forecast system.

II. How the scheme works

The satellite weighting scheme used in this experiment was chosen because it could be implemented within the framework of the analysis procedure without making major modifications to the current method. The weighting scheme was applied to satellite derived thicknesses rather than temperatures because the Flattery analysis is basically a method for simultaneously analyzing heights and winds, rather than temperatures and winds.

The Final analysis/forecast cycle consists of the following major steps:

A. Global forecast made to 6 hours.

B. Spectral analysis of 6-hour forecast to obtain guess coefficients.

C. Spectral analysis of observational data using guess coefficients as first guess.

These three steps are repeated every 6 hours. In order to incorporate the satellite weighting scheme, the following three steps were added between steps B and C above:

1. First-guess thicknesses reconstructed from spectral coefficients at satellite observation points.

2. Reconstructed guess thicknesses blended with satellite observed thicknesses.

3. Original satellite-observed thicknesses replaced by blended thicknesses in the analysis procedure.

In other words, each satellite observation was replaced in the analysis procedure by an observation consisting of a blend between satellite observation and first guess interpolated to the satellite observation point. Assuming that the error of a first-guess sounding and satellite observation is uncorrelated, a blend of the two should, on the average, be a better estimate than either individual contribution.

The blending formula chosen is a simple average, i.e., forecast sounding and observational sounding are given equal weight. Such a formula was chosen because it is simple and because 6-hour forecast soundings produced by the NMC global model have characteristic errors similar to those of experimental Nimbus 6 soundings from DST-5. When verified against radiosonde data, forecast and satellite soundings both exhibit error maxima near the surface and tropopause, and both exhibit a pronounced warm bias in the vicinity of the tropopause.

A further refinement of the satellite weighting scheme might be to make the blending formula spatially dependent. Such a scheme could make allowance for the fact that 6-hour forecasts are more accurate over continents (rich in radiosonde data coverage) than over oceans (less rich in radiosonde data coverage). However, no such spatially varying weighting scheme was tried in this experiment.

III. How the scheme was tested

The satellite weighting scheme was tested by performing analyses and forecasts over a 5-day period beginning at 00GMT August 18, 1975. This period was chosen because experimental Nimbus-6 soundings were available during this time. The Nimbus-6 sounding system is the prototype of the next generation of operational satellite sounders. A 6-hour update interval was chosen so that none of the observations would deviate from synoptic time by more than 3 hours. The analysis procedure was exactly the same as the one used in the operational Final cycle except for the addition of the satellite weighting scheme. A 6-hour forecast was made from each analysis and used as first guess for the succeeding analysis. These forecasts were produced with the operational 9-layer global model with 2.5 degree resolution. Besides Nimbus-6 soundings, all data from the operational Final cycle were used except for manually-produced bogus. The operational data base included VTPR soundings from NOAA-4 to which the satellite weighting scheme was also applied. Forecasts out to 72-hours were made with the operational 6-layer hemispheric PE model from three separate times. These forecasts were verified against radiosonde observations and against analyses. Finally, the eddy available potential energy was calculated for half the analyses (those valid at 00 and 12 GMT) using the NMC operational energy program.

Additionally, a control experiment was run for comparison with the above described experiment. The control was identical to the first experiment in every respect except that the satellite weighting scheme was omitted from the control experiment. The satellite weighting experiment and the control experiment began by using a common first guess for the first analysis at 00 GMT August 18, but thereafter the two experiments cycled independently of one another. In other words, each used its own first guess after the first 6-hour cycle. The same forecasts and verifications were produced for the control as for the satellite weighting experiment.

IV. Results

The satellite weighting scheme was judged by comparing results of the satellite weighting experiment to results of the control experiment. Verifications of 6-hour forecasts are compared in Table 1. These forecasts constitute the first guesses used in the analyses at 00 and 12 GMT. Forecasts valid at 06 and 18 GMT were not verified due to the lack of radiosonde data available at these times. Three variables--heights, temperatures, and winds--were verified at four different levels. The 6-hour forecast errors from the satellite weighting experiment are only slightly, yet consistently, smaller than those from the control. The 6-hour forecasts with satellite weighting are slightly better at all levels and for all three variables. The radiosonde stations used in the verification are located over northern North America and northern Europe. Therefore, no concrete conclusions can be drawn about the relative quality of the first guesses elsewhere. However, examination of difference fields can show how much difference there is between first guesses made with and without benefit of the weighting scheme.

Figure 1 depicts the Northern Hemisphere height differences at 500 mb between the weighting experiment guess and the control guess at the end of the 5-day test. The contour interval is 7.5 m. Except for an area of 42.5 m difference near the North Pole, the differences between the two guesses is small, about 22 m or less. Furthermore, the differences over the verification areas are about the same size as those in other areas. Similar results occur at other levels and for other times. Obviously, the two forecasts are very nearly the same, both over the verification stations and elsewhere.

Figure 2a shows the 500 mb satellite weighted, Northern Hemisphere height analysis at the end of the 5-day test period (valid at the same time as the first guess difference depicted in Figure 1). The difference between this analysis and the corresponding control is shown in Figure 2b. The differences are small and similar in magnitude to the first guess differences from Figure 1. The smallest differences (very nearly zero) are over continents rich in radiosonde observations. Small differences should be expected in such areas since both the satellite weighted and control analyses treat radiosonde data in the same way. Differences at other levels and at other analysis times are similarly small.

Since the differences between satellite weighted analyses and control analyses is so small in the Northern Hemisphere, it is difficult (probably impossible) to assess which analyses are better by any subjective means. In the Southern Hemisphere the differences are much larger but the problem of assessment is not any easier. Southern Hemisphere 500-mb height analyses valid at the end of the 5-day test period are shown in Figure 3 for both the weighted and unweighted cases. The difference between the two analyses is also depicted (Figure 3c), using a contour interval of 30m. Large differences occur over oceanic areas where very few radiosonde or surface observations are available. The largest differences occur in areas where surface observations are totally absent, as can be seen by comparing Figure 3c to the surface data coverage chart in Figure 4.

Neither analysis in Figure 3 is considered very good. For example, the deep cyclonic vortex shown on both analyses near the Antarctic coastline at about 150W is not supported by satellite imagery. In areas where large height differences exist at 500 mb, a substantial portion of the difference can be attributed to large differences at 1000 mb (Figure 5). An example can be seen in a large area of the extreme southern part of the eastern Pacific. The greater than 120m differences are due in part to large differences at 1000 mb. Remember that satellite soundings enter the analysis system in the form of height thicknesses between 1000 mb and other mandatory levels. Hence differences at 1000 mb will be reflected at other levels. The fact that the two 1000 mb height analyses (one with and one without benefit of the weighting scheme) differ so greatly, even though the input of surface data to each analysis is the same, supports the idea that many more surface observations are needed in the Southern Hemisphere to adequately define a 1000-mb reference level for satellite soundings. Apparently by changing the satellite observations slightly by using the weighting scheme, a slightly different analysis is produced. This analysis results in differences in the 1000-mb forecast. The difference probably accumulates over several cycles since the two experiments cycle independently of one another, and since no surface data enter either system in areas where the 1000-mb differences are large. Only very small differences between analyses with and without the weighting scheme occur in the Northern Hemisphere at 1000 mb where large numbers of surface reports are available nearly everywhere.

Using the NMC operational 6-layer hemispheric model, 72-hr forecasts were made for the Northern Hemisphere from three different analysis times during the 5-day test period. Forecasts were made from both the satellite weighted analyses and control analyses, making a total of six forecasts in all. All forecasts were verified against NMC operational final analyses and against radiosonde observations taken over Europe and North America. Verification against NMC analyses is in the form of S1 scores, which are tabulated in Table 2. The S1 scores are tabulated separately for 24, 48, and 72 hours and for each forecast made. In the difference column, a "+" indicates an edge for the forecast beginning from the satellite weighted analysis. Each score is an average over two grids which cover North America and Europe. Radiosonde verifications are in terms of root-mean-square errors of height, temperature, and vector wind (Table 3). Errors are tabulated separately for each forecast hour, but the three forecast cases are averaged together. Error differences preceded by a "+" indicate smaller errors for the forecasts beginning from satellite weighted analyses.

Neither the S1 scores nor the radiosonde verifications show the forecasts made from satellite-weighted analyses to be superior to those made from control analyses. The forecast model obviously is not sensitive to the small differences between analyses. The forecast differences are so small that they are almost indiscernible to the naked eye as can be seen by comparing the two 48-hour forecasts shown in Figure 6. The difference map, contoured at 30m intervals, is displayed in Figure 6c. One forecast (Figure 6a) was made from an analysis using the weighting scheme; the other (Figure 6b) was made from an unweighted analysis. The verifying analysis (not shown) reveals that the two 48-hour forecasts resemble each other much more closely than either resembles the real atmosphere.

Finally, the temperature variances of several analyses were compared by computing the eddy available potential energy (AE) for all the weighted and unweighted analyses valid at 00 and 12 GMT during the 5-day test period. One of the criticisms leveled against soundings derived from Nimbus-6 data is that they underestimate the temperature variance of the real atmosphere. In other words, satellite soundings tend to underestimate the amplitudes of meteorological systems. It was hoped that weighting the satellite soundings with forecast soundings might increase the AE to a level closer to that of an analysis made without satellite soundings. Such a result was achieved as can be seen from Figure 7. However, the increase in eddy available potential energy is rather small.

The disappointingly small increase is probably due primarily to two factors. First of all there are an overwhelmingly large number of satellite observations compared to radiosonde observations. The ratio averages out to three to one. Secondly, the first guesses to the satellite-weighted analyses have less AE than the analyses from which the forecasts began. This loss of AE is due primarily to vertical interpolations into and out of the model coordinate system. However, the AE of these first guesses is still substantially greater than analyses produced using only satellite data.

V. Conclusion

The 6-hour first guess forecasts made from analyses using the satellite weighting scheme exhibit slight but consistent superiority over those 6-hour first guess forecasts made without benefit of the weighting scheme. Differences between analyses made with and without the weighting scheme are small in the Northern Hemisphere, however, and difficult to assess. Furthermore, 3-day forecasts made from both types of analyses in the Northern Hemisphere show no significant differences, probably because initial analysis differences are so small and because the forecast model used is insensitive to such small differences. Analysis differences in the Southern Hemisphere are considerably larger than in the Northern Hemisphere. However, analyses made with the weighting scheme are not considered superior to those made without it. A large percentage of the difference is due to inadequate definition of the 1000 mb reference level.

The temperature variance, which is known to be underestimated in analyses made using satellite soundings, is increased to a slightly better level when the satellite weighting scheme is used. However, it remains at a level substantially below that of the real atmosphere.

Finally, it should be pointed out that using the satellite weighting scheme is fairly inexpensive. Weighting satellite soundings with forecast soundings adds an average of 7 seconds of CPU time and about 1 minute of wall time to each analysis performed on an IBM 360/195 computer. In view of its modest cost, implementation of the satellite weighting scheme in the operational Final cycle is probably a desirable step. The weighting scheme permits a more systematic way of handling satellite thickness observations and would probably result in slightly improved analyses and first-guess forecasts.

Table 1a. RMS 6-hour forecast errors verified at 80 Northern Hemisphere radiosonde stations at 850 mbs. SW is satellite weighting experiment.

Valid Time	Height (m) SW	Height (m) Control	Temp (°C) SW	Temp (°C) Control	Vector Wind (kts) SW	Vector Wind (kts) Control
18/12Z	21.4	22.0	2.6	2.6	8.5	8.7
19/00Z	17.1	16.7	2.7	2.8	9.9	10.0
19/12Z	16.6	16.9	1.8	1.8	10.5	10.4
20/00Z	16.0	17.0	2.9	3.1	8.6	8.7
20/12Z	17.1	17.3	2.5	2.5	9.0	9.2
21/00Z	22.0	21.1	2.4	2.7	9.6	9.7
21/12Z	20.0	21.2	1.9	2.0	10.4	10.5
22/00Z	21.6	20.3	2.2	2.3	8.8	8.8
22/12Z	19.5	19.3	2.0	2.1	11.1	11.1
23/00Z	19.1	19.8	2.5	2.6	11.8	11.7
Average	19.0	19.2	2.4	2.5	9.8	9.9

Table 1b. RMS 6-hour forecast errors verified at 80 Northern Hemisphere radiosonde stations at 500 mbs. SW is satellite weighting experiment.

Valid Time	Height (m) SW	Height (m) Control	Temp (°C) SW	Temp (°C) Control	Vector Wind (kts) SW	Vector Wind (kts) Control
18/12Z	29.5	32.2	1.6	1.8	10.1	10.6
19/00Z	23.1	23.3	1.4	1.5	11.2	11.1
19/12Z	21.6	24.5	1.6	1.6	12.4	12.9
20/00Z	25.9	26.6	1.4	1.5	10.7	10.7
20/12Z	25.7	26.6	1.9	2.0	10.2	10.3
21/00Z	22.1	25.1	1.4	1.7	9.8	9.9
21/12Z	26.4	27.5	1.4	1.4	11.4	11.6
22/00Z	25.6	24.6	1.5	1.5	10.4	10.3
22/12Z	29.5	30.0	1.7	1.6	12.3	12.4
23/00Z	26.6	26.0	1.6	1.6	12.7	12.7
Average	25.6	26.6	1.5	1.6	11.1	11.2

Table 1c. RMS 6-hour forecast errors verified at 80 Northern Hemisphere radiosonde stations at 300 mb. SW is satellite weighting experiment.

Valid Time	Height (m) SW	Height (m) Control	Temp (°C) SW	Temp (°C) Control	Vector Wind (kts) SW	Vector Wind (kts) Control
18/12Z	43.9	47.2	2.3	2.6	14.8	15.2
19/00Z	32.5	32.6	2.2	2.3	18.1	18.5
19/12Z	35.9	39.8	2.5	2.7	17.5	18.0
20/00Z	34.9	34.0	2.6	2.7	20.4	21.4
20/12Z	46.7	48.7	3.2	3.3	15.0	15.1
21/00Z	32.2	38.8	2.4	2.6	18.9	19.6
21/12Z	33.8	35.8	2.9	2.9	19.7	19.7
22/00Z	39.5	41.2	2.2	2.4	17.2	17.7
22/12Z	40.6	41.1	2.7	2.9	16.5	16.6
23/00Z	33.2	31.6	2.2	2.2	24.6	24.7
Average	37.3	39.1	2.5	2.7	18.3	18.6

Table 1d. RMS 6-hour forecast errors verified at 80 Northern Hemisphere radiosonde stations at 100 mbs. SW is satellite weighting experiment.

Valid Time	Height (m) SW	Height (m) Control	Temp (°C) SW	Temp (°C) Control	Vector Wind (kts) SW	Vector Wind (kts) Control
18/12Z	46.0	51.6	1.5	1.8	9.8	10.3
19/00Z	32.3	46.5	1.6	2.3	8.5	8.9
19/12Z	41.7	53.1	1.4	1.7	8.6	9.9
20/00Z	46.6	52.5	1.6	2.1	9.6	11.0
20/12Z	42.6	42.4	1.6	1.6	8.7	9.5
21/00Z	44.9	56.0	1.7	2.1	8.5	9.5
21/12Z	43.1	50.6	1.4	1.5	9.4	10.2
22/00Z	46.2	54.4	2.1	2.2	8.6	9.6
22/12Z	38.5	39.1	1.7	1.7	13.0	13.8
23/00Z	40.7	45.5	1.8	1.9	8.8	9.8
Average	42.3	49.2	1.6	1.9	9.4	10.2

Table 2. 6-level forecast S1 scores, North America and Europe combined. SW is satellite weighted; NSW is control.

From 00 GMT Aug. 20, 1975

Level (mb)	24 hr SW	24 hr NSW	24 hr Dif	48 hr SW	48 hr NSW	48 hr Dif	72 hr SW	72 hr NSW	72 hr Dif
850	44	43	(-1)	61	62	(+1)	69	69	(0)
500	34	34	(0)	48	47	(-1)	52	53	(+1)
300	37	37	(0)	47	47	(0)	55	55	(0)
100	58	59	(+1)	59	61	(+2)	64	63	(-1)

From 00 GMT Aug. 21, 1975

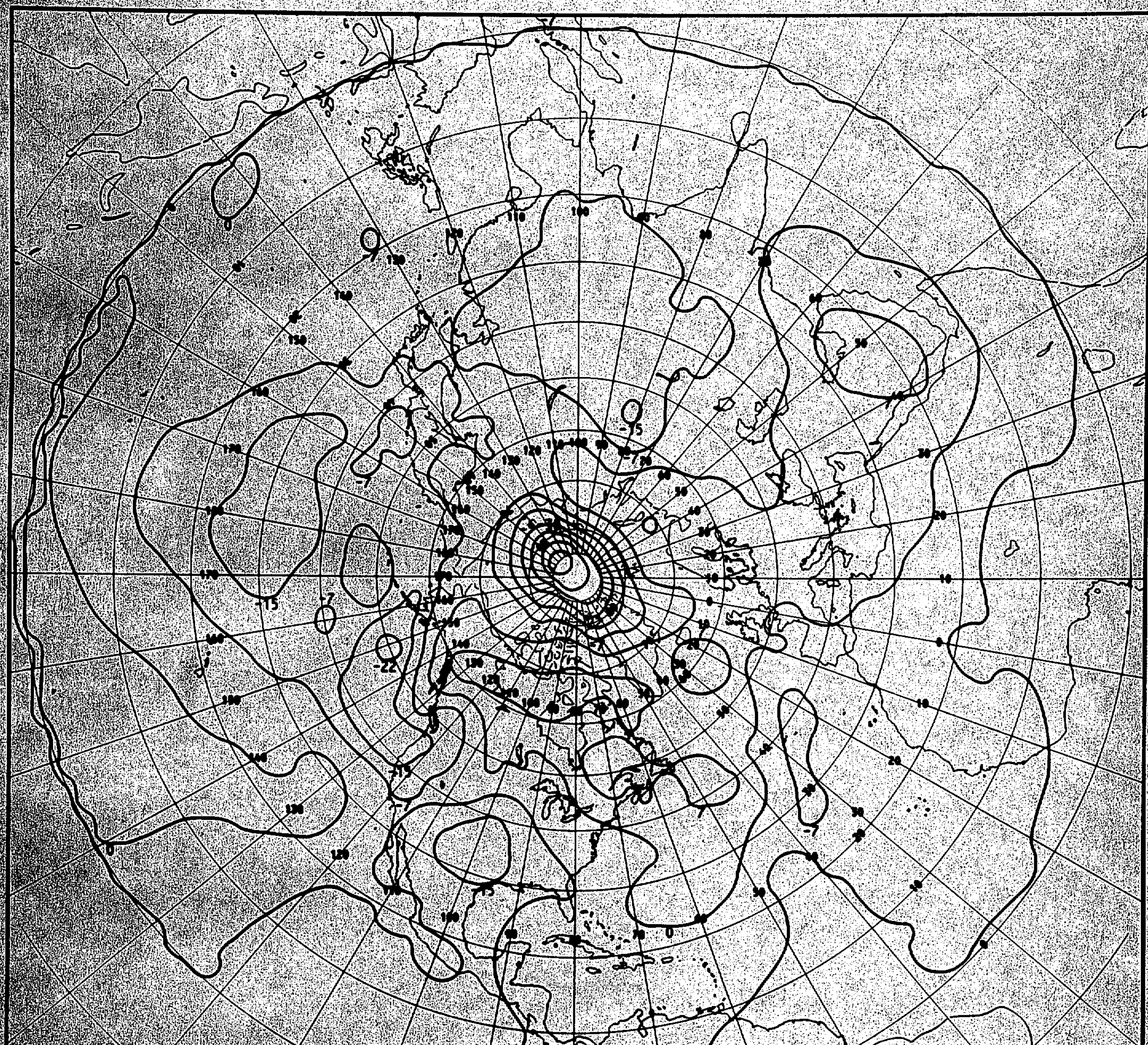
Level (mb)	24 hr SW	24 hr NSW	24 hr Dif	48 hr SW	48 hr NSW	48 hr Dif	72 hr SW	72 hr NSW	72 hr Dif
850	51	51	(0)	64	63	(-1)	70	69	(-1)
500	38	38	(0)	51	50	(-1)	52	51	(-1)
300	39	39	(0)	53	53	(0)	51	49	(-2)
100	56	56	(0)	63	62	(-1)	66	66	(0)

From 00 GMT Aug. 23, 1975

Level (mb)	24 hr SW	24 hr NSW	24 hr Dif	48 hr SW	48 hr NSW	48 hr Dif	72 hr SW	72 hr NSW	72 hr Dif
850	50	51	(+1)	56	56	(0)	68	70	(+2)
500	36	36	(0)	43	41	(-2)	55	55	(0)
300	35	36	(+1)	44	43	(-1)	53	54	(+1)
100	52	52	(0)	54	55	(+1)	66	65	(-1)

Table 3. RMS 6-level PE forecast errors, 74 Northern Hemisphere radiosonde stations. SW - satellite weighted; NSW - control. Average of three cases.

Level (mb)	Height (m)			Temp (°C)			Vector Wind (kts)		
	SW	NSW	Dif	SW	NSW	Dif	SW	NSW	Dif
				24 hr					
850	25.8	26.6	(+.8)	2.4	2.5	(+.1)	11.9	11.8	(-.1)
500	27.3	27.7	(+.4)	1.9	1.9	(0)	13.2	13.3	(+.1)
300	45.5	45.2	(-.3)	2.0	2.0	(0)	23.3	23.7	(+.4)
100	49.4	47.9	(-1.5)	4.8	4.7	(-.1)	13.0	13.6	(+.6)
				48 hr					
850	40.5	39.2	(-1.3)	3.1	3.3	(+.2)	15.0	15.1	(+.1)
500	53.5	52.2	(-1.3)	2.6	2.6	(0)	15.8	15.8	(0)
300	81.4	79.7	(-1.7)	2.9	2.9	(0)	28.8	29.1	(+.3)
100	82.8	79.3	(-3.5)	6.1	6.0	(-.1)	16.8	16.9	(+.1)
				72 hr					
850	49.6	49.7	(+.1)	3.7	3.8	(+.1)	18.2	17.9	(-.3)
500	70.9	72.3	(+1.4)	3.6	3.5	(-.1)	21.0	21.1	(+.1)
300	111.3	113.0	(+1.7)	3.5	3.6	(+.1)	36.7	36.9	(+.2)
100	98.7	97.9	(-.8)	6.5	6.5	(0)	19.8	19.6	(-.2)



SW -NSW DIF 500.00 MB HGT FOR 006 HRS AFTER 18Z 22 AUG 75 WMC/NMC WASHINGTON.

Figure 1. SW - satellite weighted; NSW - control.

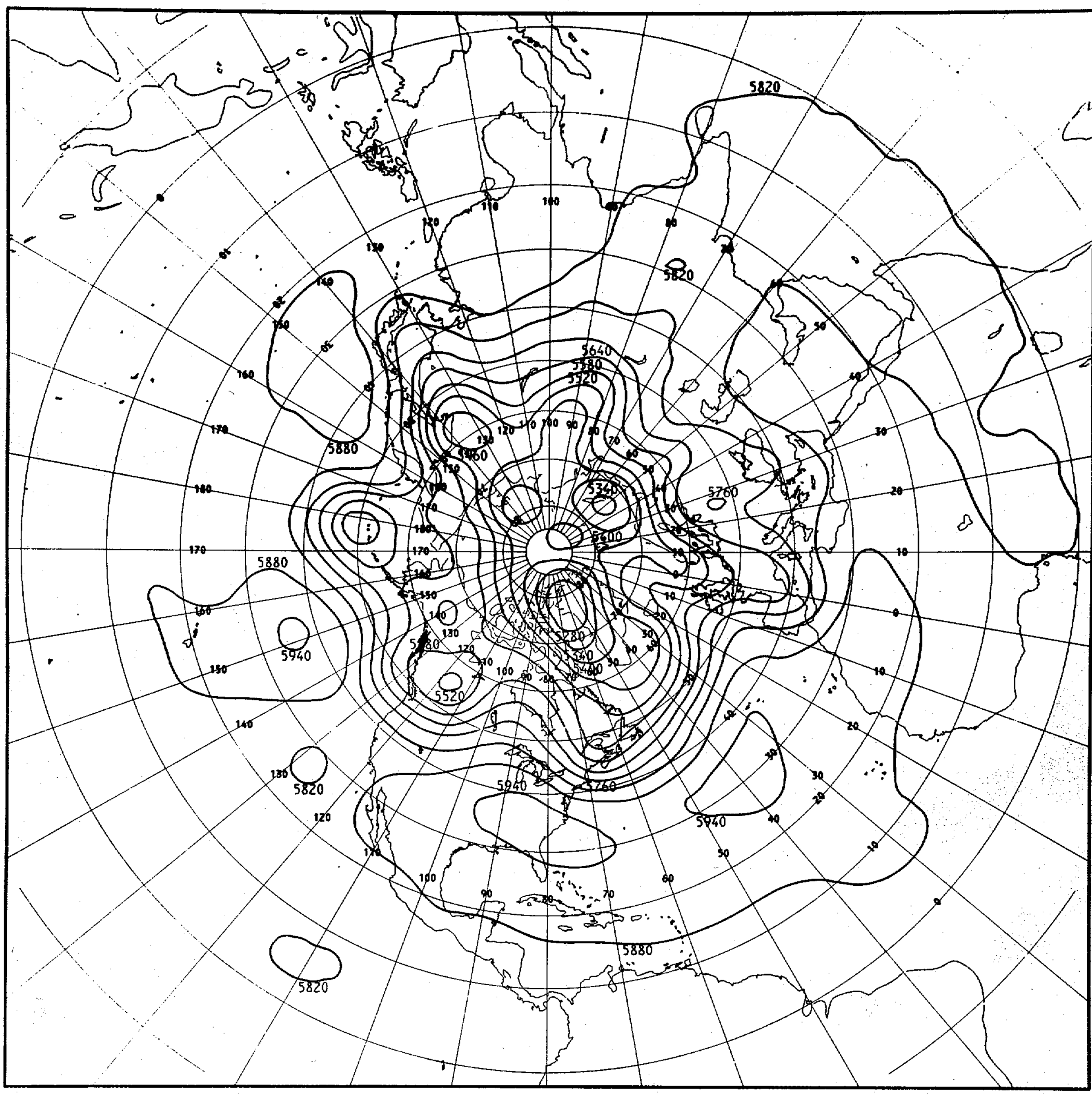


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Figure 2a.

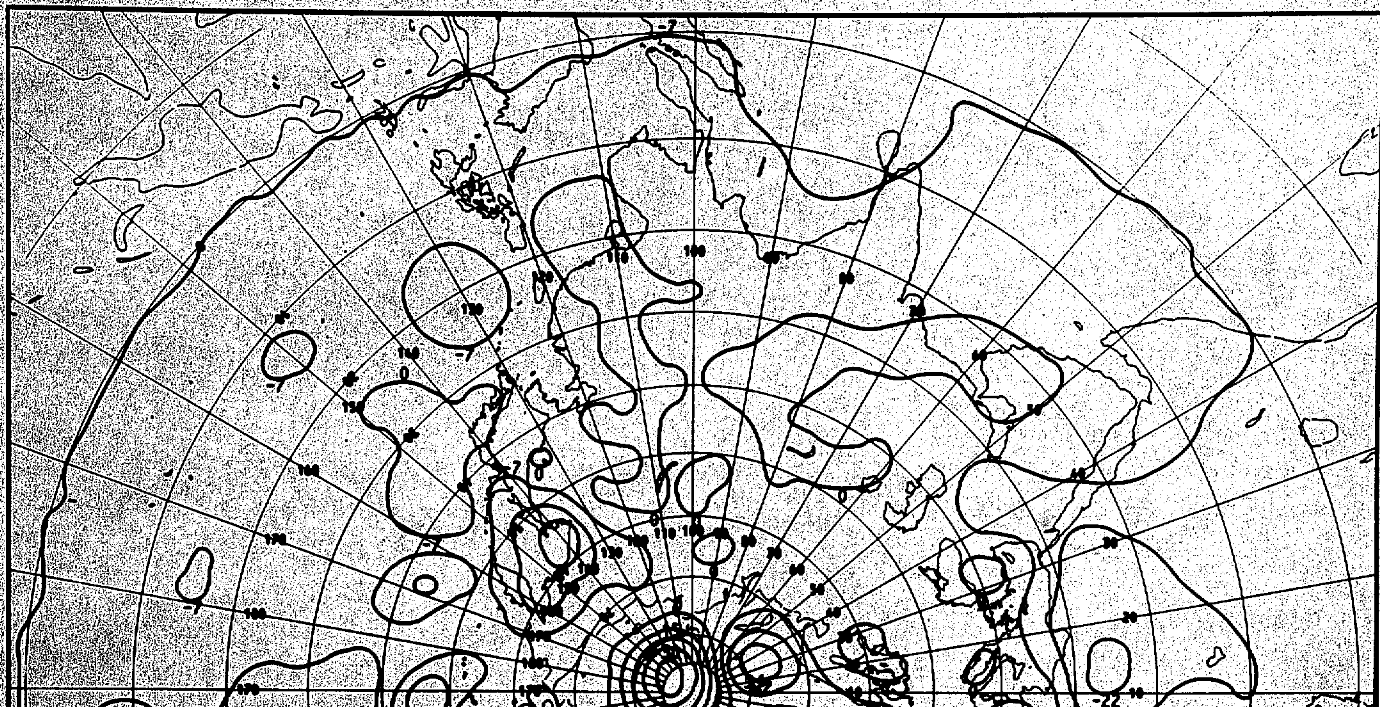

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Figure 2b.

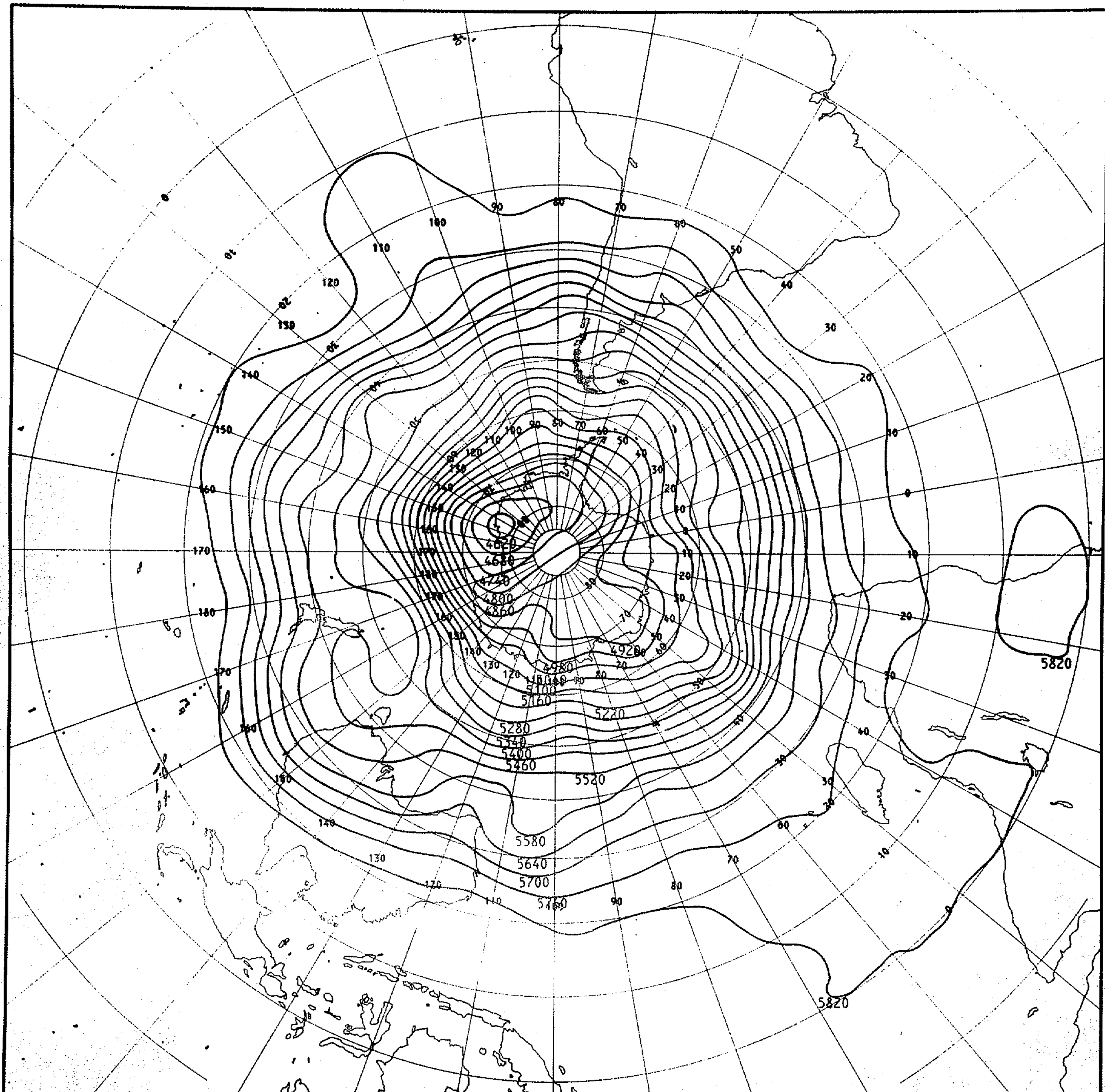

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Figure 3a. Satellite weighted analysis.

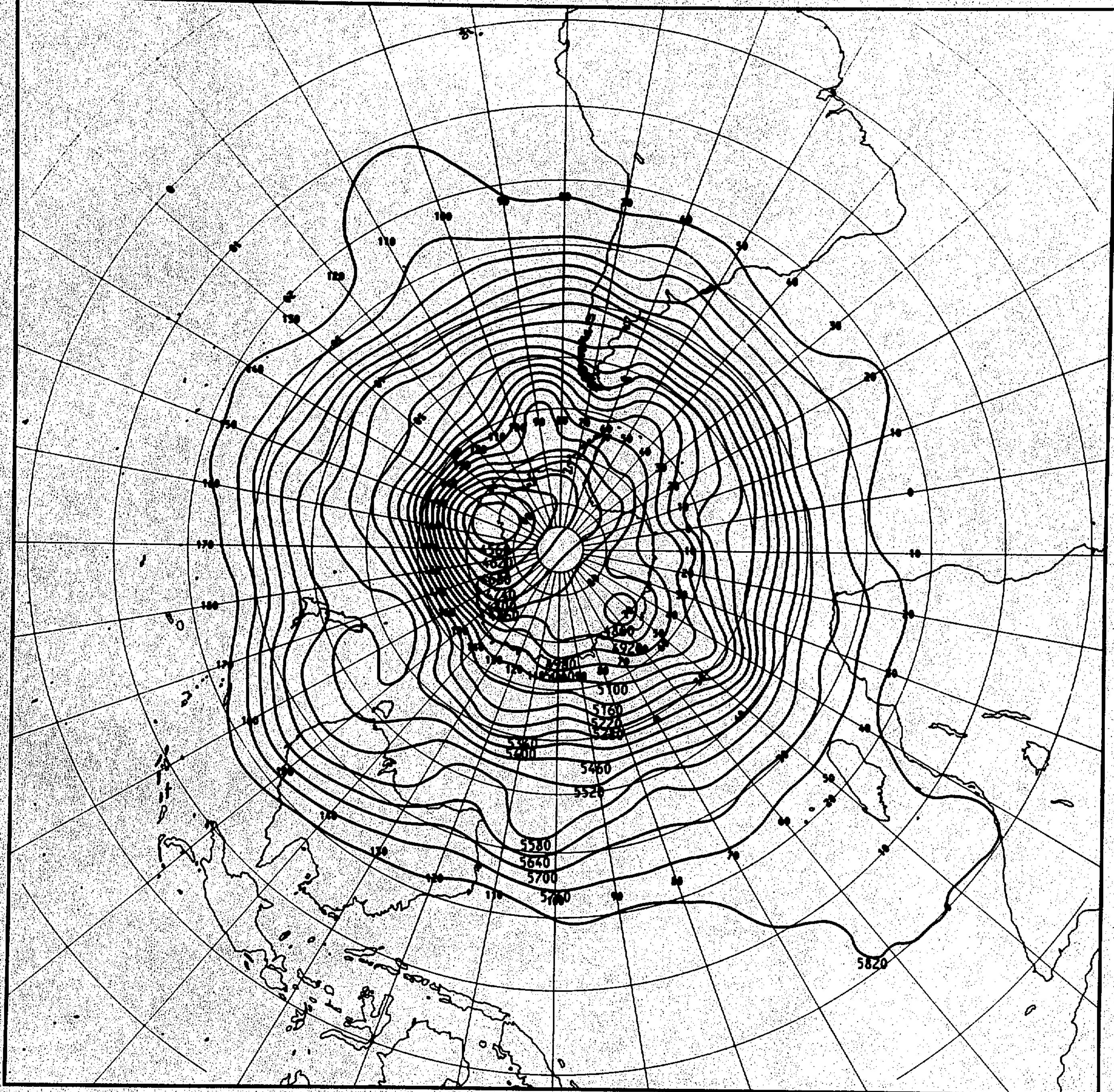

Figure 3b. Control analysis.

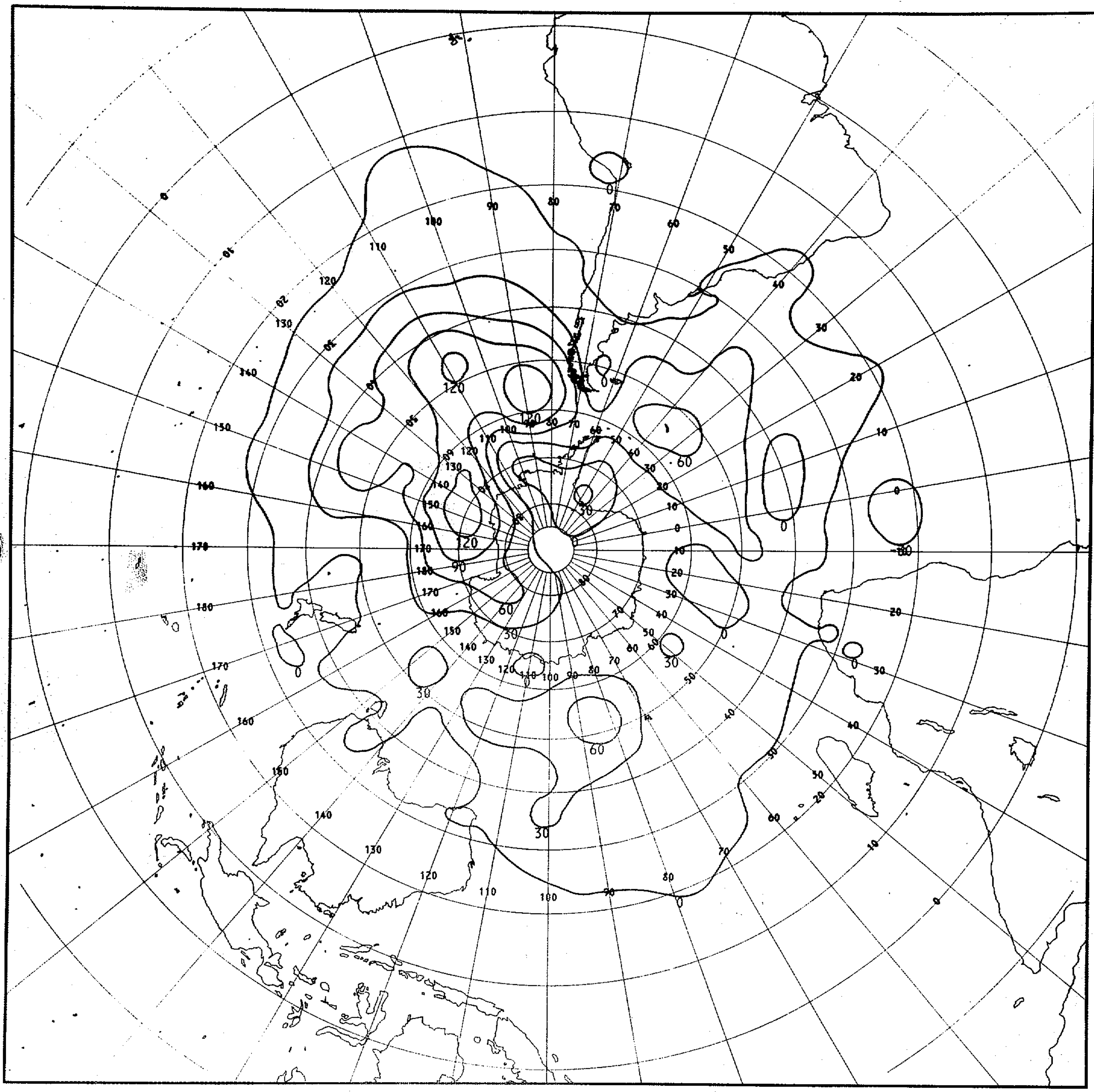

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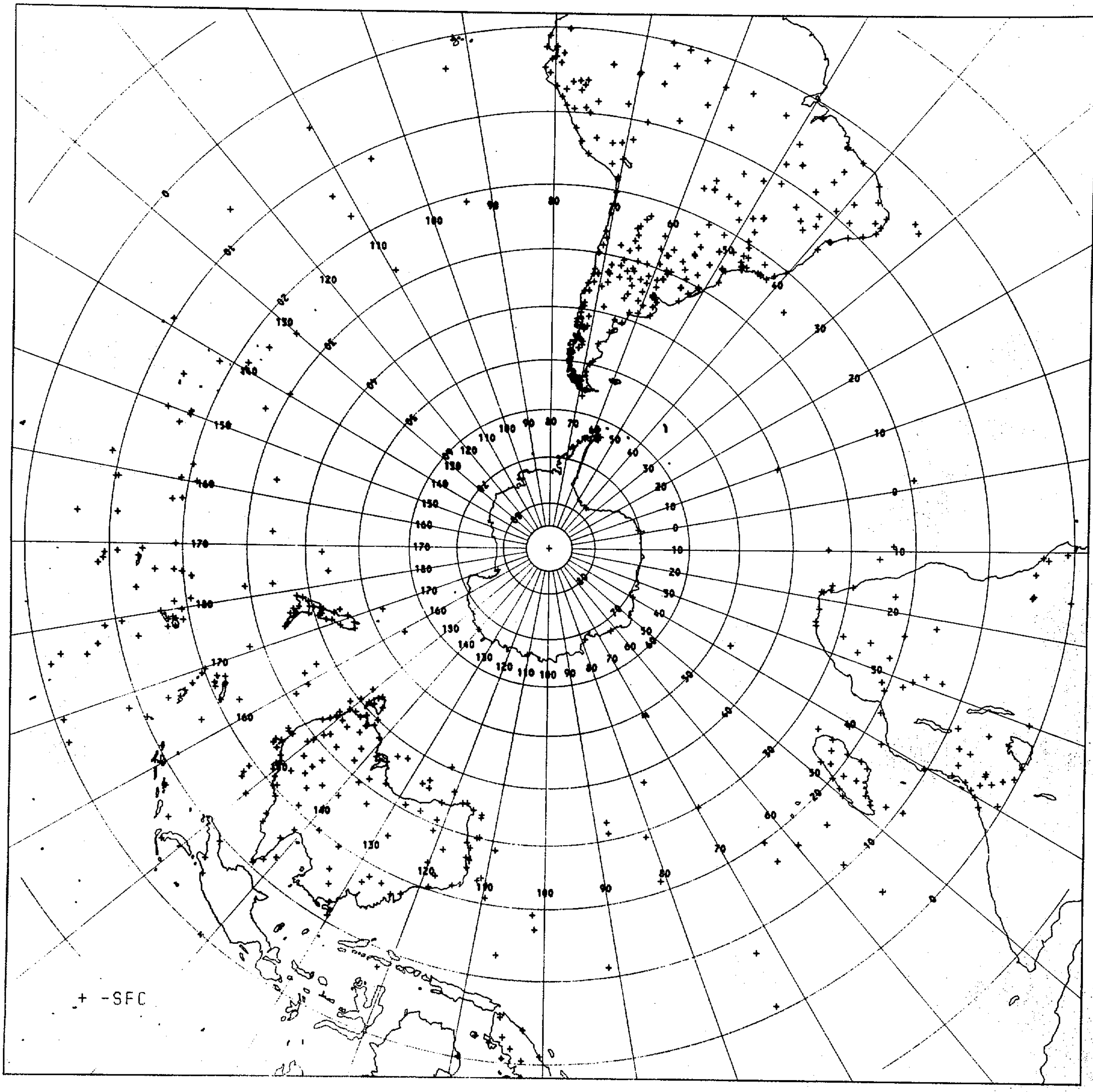
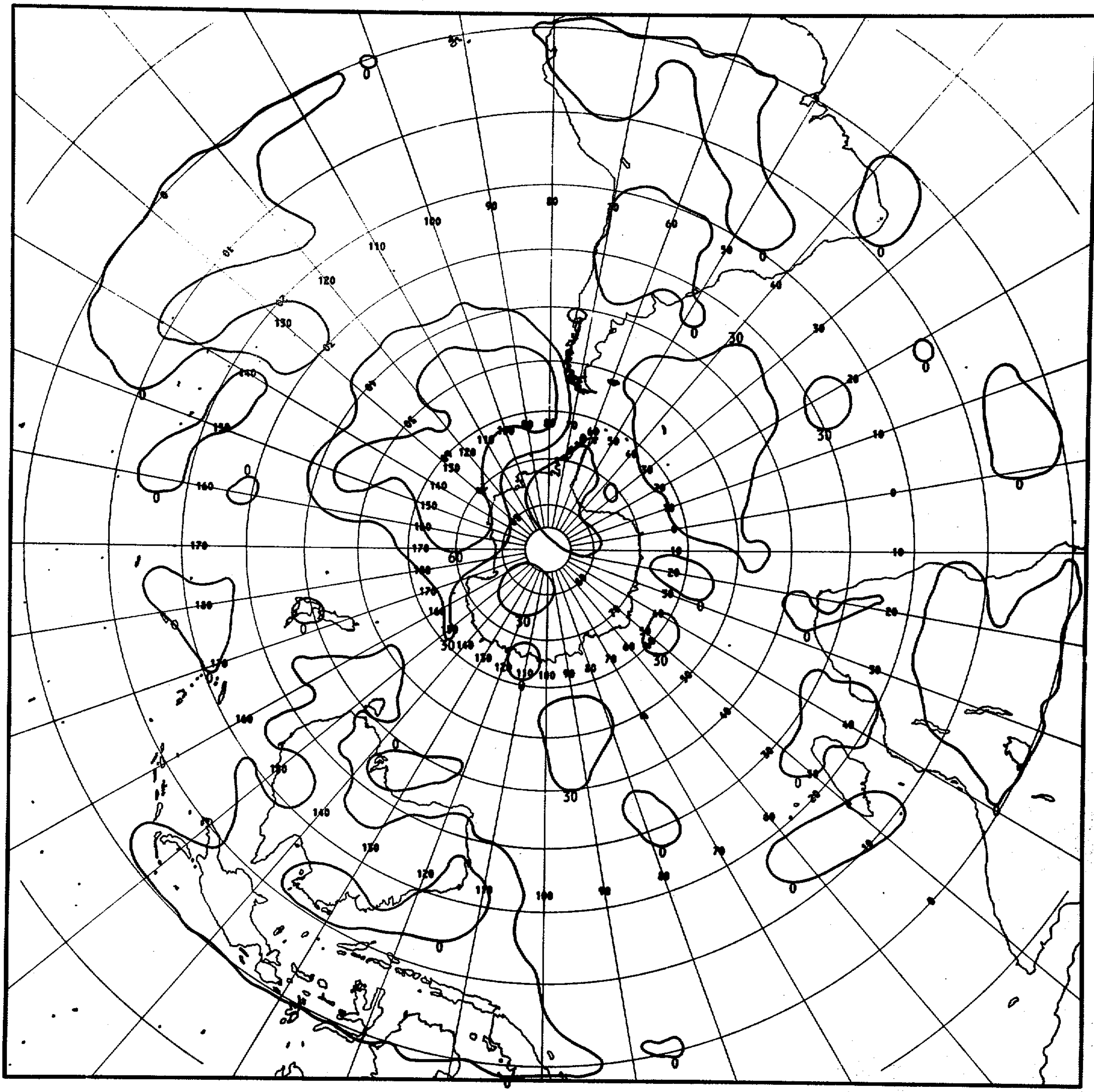
Figure 3c.



S.H. SURFACE DATA COVERAGE ON

NMC2SFC2750823009999WASH

Figure 4



SW -NSW DIF 1000.0 MB HGT FOR 000 HRS AFTER 00Z 23 AUG 75 WMC/NMC WASHINGTON.

Figure 5.

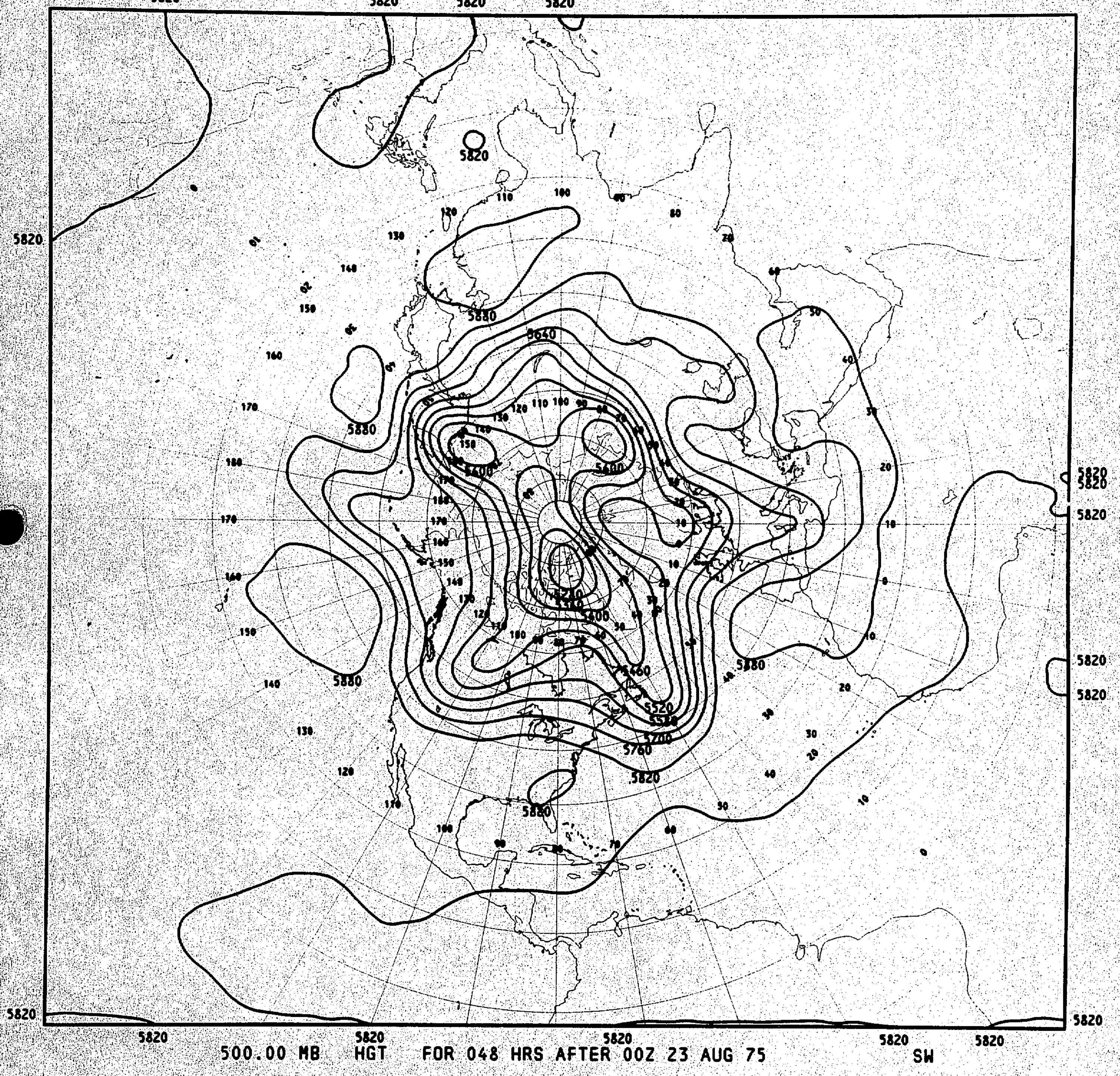


Figure 6a. Forecast from satellite weighted analysis.

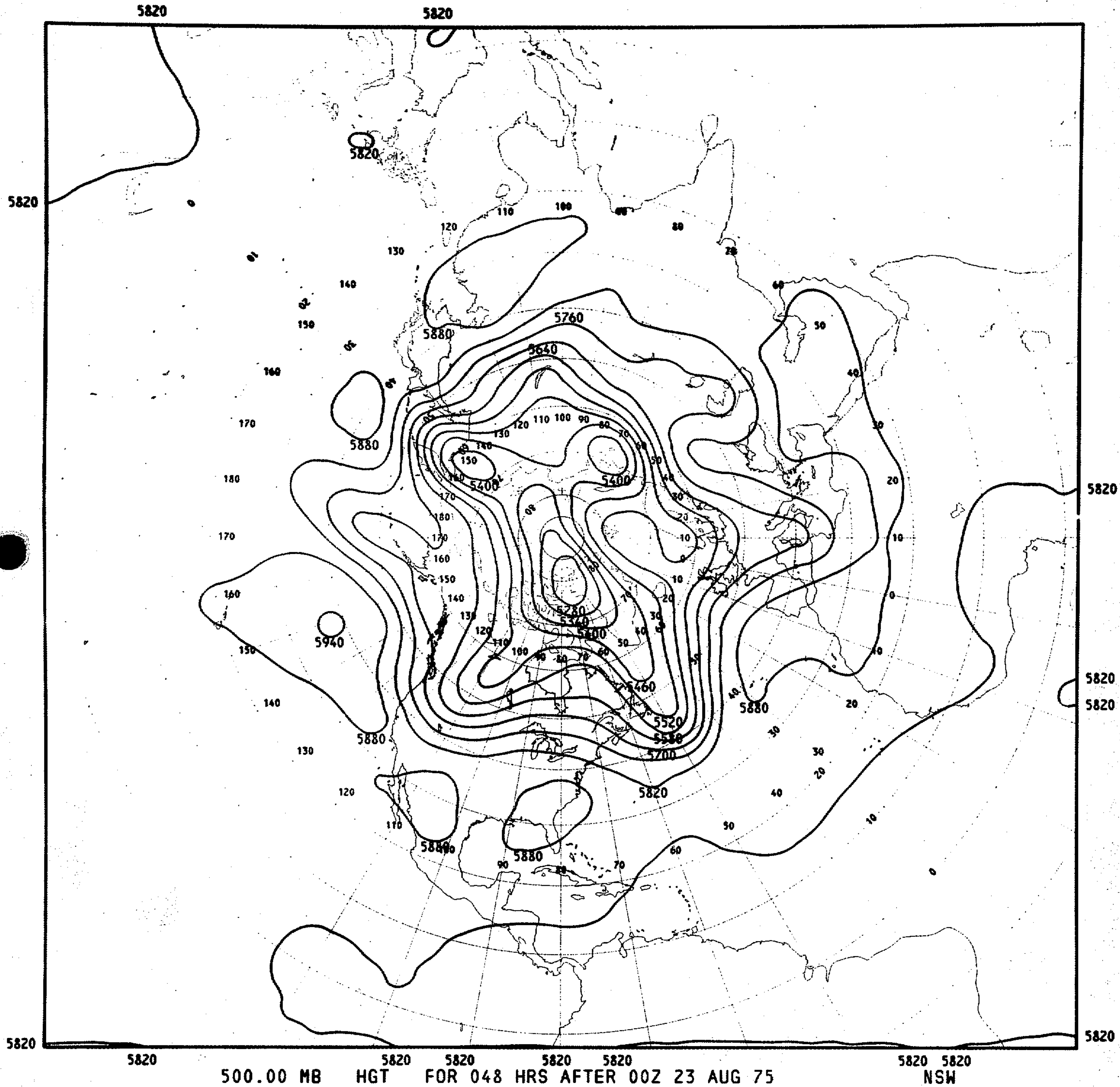


Figure 6b. Control forecast

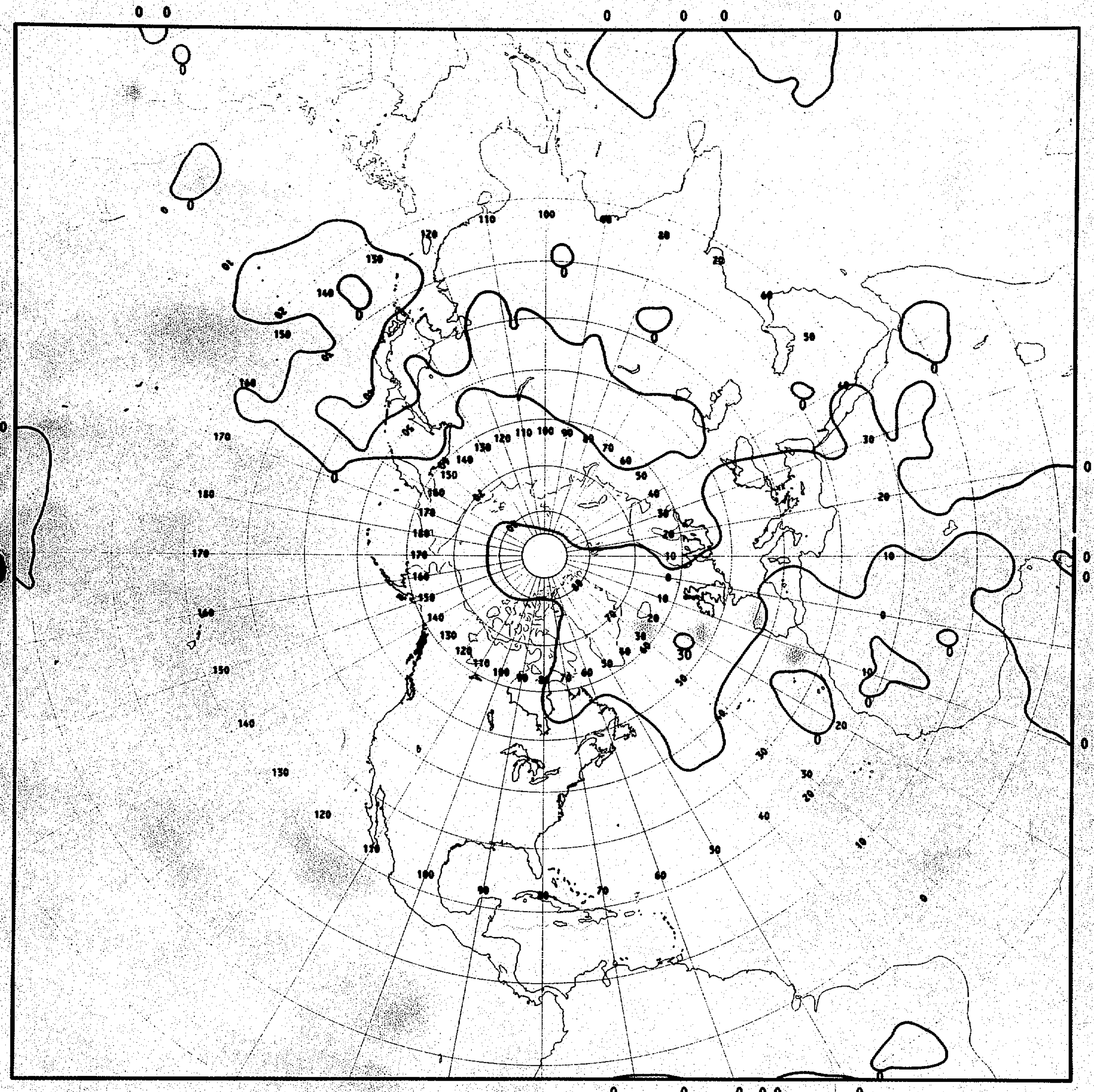


Figure 6c. Difference in meters between height fields in 6a and 6b.